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This report describes work done on mental imagery, short term memory scanning, language-related mental tasks, and visual attention. In the field of mental imagery it was found that searching memory to determine if or if not a visual form had been seen before, there is a change in the state of the occipital (visual) cortex. This change is commensurate in time with the reaction time indicating that the mental search is complete. It was also shown that engaging in language related tasks does not have a similar effect on visual cortex, but it does have a similar effect on temporal cortex. Using visually presented words to initiate a mental imaging task results in related changes in activity of visual cortex, and also temporal cortex. However, when the same words are used in rhyming tasks, the major effect is on left temporal cortex. Using acustically presented words in a similar task produces parallel results, although the effects on visual cortex are not so reliably found across subjects, and both imaging and rhyming affect temporal cor-

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tex, suggesting a role for language in imagery. In another memory scanning experiment subjects attempted to determine if a musical note was or was not a member of a set of previously heard notes. The duration of the change in brain state, implied by suppression of alpha band activity, was related to the size of the memory set, provided that it was recorded in a region that picked up activity originating in temporal areas, probably auditory cortex. In the visual attention work we are attempting to complete the analysis and full written report on work conducted under another AFOSR contract. Clearly, directing visual attention to different spatial positions involves shared resources rhather than independent multiple resources, but this appears only when task difficulty is calibrated. The effects of shared attention are present in activity originating near the parietal occipital boundary, but these do not seem to acount fully for effects of shared attention on behavior, as revealed in attention operating characteristics.

Technical Report

Attention, Imagery, and Memory: A Neuromagnetic Investigation

by Lloyd Kaufman and Samuel J. Williamson

Neuromagnetism Laboratory
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and Center for Neural Science
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Introduction

This report covering work accomplished between 3/1/89 and 2/28/90 is submitted in accord with the requirements of Contract No. F49620-88-K-004 between AFOSR and New York University. It covers a broad range of topics, and work on each of them is briefly summarized in this document. More details of the accomplishments are contained in the appended reprints and preprints of papers and chapters.

Accomplishments

Role of Visual Cortex in Mental Imagery

One of the main themes of this project is to enhance our understanding of the processes underlying the phenomena identified with the term *mental imagery*. In this report period strong evidence was obtained that the human visual cortex participates in mental imagery. This was achieved by a novel protocol in which a subject mentally compared an abstract figure presented on a screen with those shown previously, and he was instructed to press one reaction time button if it matched a member of the memory set and another button if it did not. Neuromagnetic measurements revealed a pronounced localized suppression of power in the alpha bandwidth, lasting for more than 1 second. The change in power distribution of the neuromagnetic field across parietal and occipital scalp gave evidence that neuronal sources of alpha were preferentially suppressed during that period, and that these sources lie within visual cortex. Initial studies with increasing size of the memory set show a positive correlation between the increase in duration of suppression and increase in reaction time, in agreement with the classic Sternberg paradigm. Additional evidence was obtained that the suppression is specifically visual and not a generalized attentional affect. Subjects engaged in a similar memory search task, but the stimuli were visually presented words, and not visual forms. In this case the suppression duration was the same when subjects actually scanned memory to make the decision as it was when they simply pressed a button to indicate that they had seen the "probe" word.

Verbal versus Imaging Tasks

To follow-up on the previous study, which was published in *Cognitive Neuroscience* (reprint appended), we also presented subjects with visual words. They were given one of two different instructions. In one case they were to try and form a mental image of the object represented by the word. In the other case they were to find a word in memory that rhymed with the presented word. In the latter case suppression over occipital areas was only momentary,

lasting for no longer than about 500 ms. However, when engaged in the imagery task the suppression of occipital alpha was prolonged and was commensurate with the time taken for the subject to press a button indicating formation of the image. This work was also published and a reprint is appended, However, it has now been extended using a somewhat modified Sternberg procedure with the same stimuli. It was found that alpha suppression originating in the left temporal area varies with the time needed to complete the language related task, while both occipital and temporal areas are involved in imagery related tasks. While beta suppression also occurred, its duration did not seem to be correlated with either task. This is consistent with the finding of Kaufman, Schwartz, Salustri, and Williamson (see reprint) that alpha and beta have at least partially independent sources. This work is now being written up for publication.

Acoustically Presented Words

A complementary study has been concluded in which words were presented acoustically. In this case suppression was observed in the alpha band over the occipital area, but not uniformly across subjects. However, alpha was consistently suppressed over the left temporal area, whether subjects were instructed to form images of objects represented by the words, or determine if the heard word did or did not rhyme with a previously heard word. This suggests that subjects employ articulatory mechanisms, even in a nominal "mental imagery" task. These results are consistent with the hypothesis that an area of cortex in temporal the temporal lobe supports spontaneous activity within the alpha bandwidth, and this area participates in the process of silent rhyming, or perhaps more generally speech. These data are still being fully analyzed.

Visual Attention

Data from a study of spatial visual attention, collected under the aegis of our previous AFOSR URI program, is now being fully analyzed and a paper is being prepared. Midlatency components (approximately 140 msec) of visual responses to stimuli on either side of a fixation point are enhanced if the subject attends to those stimuli. So are later components up to about 300 msec. These data suggest that the sources of the components affected by attention are not localized to primary visual cortex, but appear to originate near the occipital-parietal boundary. However, that tentative conclusion depends upon the level of statistical significance of the dipole fits, which are not yet compete. When only two levels of task difficulty were employed, subject accuracy suggested that attending to two different locations at the same time can be done as well as when subjects attend to the two locations separately. However, with increased task difficulty Attention Operating Characteristics (AOC) indicate that a shared resource was involved. Up to now, however, our attempts to apply AOC analytical methods to event related field components have not been successful. However, it is too early to conclude that the field components apparently affected by attention are not fully reflective of behavioral data such as response accuracy or RT. This work continues.

Memory Search for Tones

We have completed a memory search study employing the Sternberg paradigm using musical tones. Subjects listened to a series of 1, 3, or 5 tones, and then , 2 second later, heard a probe tone and had to decide if it was or was not a member of the memory set. Reaction times revealed the classic pattern of results. RT increased linearly with set size. The alpha suppression effect described above was also found. However, the duration of suppression increased with set size only over the regions where auditory evoked responses are strongest, suggesting that the regions

involved in this memory scanning task include auditory cortex. Occipital alpha was also suppressed, but it was inconsistently related to set size. Since suppression duration over the temporal area in this experiment was always a constant percentage of time greater than RT, it suggests that recovery from suppression depends upon the duration of the brain state indicated by the suppression phenomenon. EEG electrodes along the midline also revealed similar suppression effects, but these could not be localized to any specific area. Beta suppression also occurred, but even over the temporal areas its duration was not systematically related to set size. This experiment is completed, and a paper is in preparation.

Theory of the Mirror Effect in Recognition Memory

This project provided partial support for a theoretical study of the mirror effect in recognition memory. A preliminary preprint is attached. This work has implications for future neuromagnetic studies on this project which will attempt to elucidate neural processes underlying forgetting phenomena.

Invited Talks

17 Jan *Magnetism of the Brain*, Seminar on Physics of the Brain, National Association of Science Writers and the American Institute of Physics, San Francisco, California.

31 Jan *Neuromagnetism: A Bridge between Physiology and Perception*, Western, Eastern and Alpine EEG Conference, Park City, Utah.

1 May *Magnetism and the Brain*, Seminar on Physics and the Brain, American Institute of Physics, D.C. Science Writer's Association, and the National Association of Science Writers, Washington, DC.

5 May *Neuromagnetism: A Bridge Physics Provides from Physiology to Perception*, Solid State Seminar, Departments of Applied Physics, Chemical Engineering, Electrical Engineering, and Mechanical Engineering, Yale University, New Haven, Connecticut.

29 May *Neuromagnetic Studies of Sensory Functions and Mental Imagery*, Plenary Session, EPIC IX - Ninth International Conference on Event Related Potentials of the Brain, Noordwijk, The Netherlands, May 28-June 3.

12 July *Localization of Brain's Response*, The American /academy of Clinical Neurophysiology Boston, Mass. July 9-12, 1989

9 Sept *Intracranial Localization by Magnetoencephalography*, Advanced Workshop on Topographic EEG and EP Analysis, International Society for Brain Electromagnetic Topography, St. Vincent, Val d'Aosta, Italy, Sept 7 - 11.

27 Sept *Magnetic Studies of the Brain – from Physiology to Cognition*, Physical Science Seminar, Bellcore Corporation, Red Bank, New Jersey.

9 Nov *Measurements of Magnetic Fields from Living Tissues*, New Horizons in Physics Lecture Series, The College at New Paltz/SUNY, New Paltz, New York.

6 Dec *Biophysical Basis of MEG*, Clinical Advances in Magnetoencephalography (MEG), American Epilepsy Society Satellite Symposium, Boston, Massachusetts.

7 Dec *Localization of Brain Function by Neuromagnetic Techniques*, Department of Medical Physics Seminar, Memorial Sloan Kettering Cancer Center, New York City.

8 Jan, 90 *Neuromagnetic Investigations of Human Sensory Systems*, Biophysics Seminar, University of Rio de Janiero, Rio de Janiero, Brazil.

11,12 Jan Four lectures: *Introduction to Biomagnetism*; *Biosusceptometry*; *Biomagnetic Source Modeling*; and *Neuromagnetism*. The First University of São Paulo Biophysics-Medical Physics Workshop for South America: New Trends in Chemical, Biological, and Medical Physics Research. Ribeirão Preto, SP, Brazil.

25 Jan *Magnetic Fields of the Brain*, Annual Meeting of the American Physical Society and American Association of Physics Teachers, Atlanta, Georgia.

7 Feb *Neuromagnetic Studies: From Physiology to Cognition*, Colloquium, Department of Physics, City College of the City University of New York, New York City.

8 Feb *Magnetic Localization of Human Brain Functions*, Biophysics Section of the New York Academy of Sciences, New York City.

29 Mar *Neuromagnetism*, Colloquium, Department of Physics, Polytechnic University, Brooklyn.

31 Mar *Magnetic Characterization of Brain Function – Epilepsy Today, Alzheimer's and Sechzophrenia Tomorrow*, Plenary Session, Medical Alumni Day, New York University School of Medicine.

20 Apr *Advances in Superconducting Biomagnetic Instrumentation*, Seminar, Superconducting Technology, Inc., Santa Barbara, California.

21 Apr *Bioelectricity and Biomagnetism in the Central Nervous System*, Workshop on Bioelectricity and Biomagnetism in Clinical Medicine: What is it, Where is it going, is it practical and affordable?, Little Company of Mary Hospital, Torrance, California.

4 May *Neuromagnetic Localization of Sensory and Cognitive Functions*, Third Swiss EEG-EP Mapping Meeting, Department of Neurology, University Hospital, Zürich, Switzerland, May 4-5.

23 May *Neuromagnetism: A Bridge that Physics Provides between Physiology and Cognition*, Seminar, Department of Physics, Universidade de Lisboa, Portugal.

1 June *Recent Advances in Neuromagnetism*, Seminar, Center for Neuromagnetism, Veterans Administration Hospital, Albuquerque, New Mexico.

4 June *Recent Advances in Neuromagnetism*, Seminar, Neuromagnetism Laboratory, Life Sciences Division, Los Alamos National Laboratory, Los Alamos, New Mexico.

Publications from this Research

"Introduction to Cerebral Modeling"
S.J. Williamson
In: *Advances in Biomagnetism – Functional Localization: A Challenge for Biomagnetism*, S.N. Erné and G.L. Romani, Eds. (World Scientific, Singapore, 1989), pp. 121 - 145.

"Neuromagnetic Localization of Neuronal Activity in Visual and Extra-Visual Cortex"
L. Kaufman and S.J. Williamson
In: *Vision and the Brain: The Organization of the Central Visual System*, Raven Press, New York, 1990.

"Theory of Neuroelectric and Neuromagnetic Fields"
S.J. Williamson and L. Kaufman
In: *Advances in Audiology, Vol. 6: Auditory Electric and Magnetic Fields*, F. Grandori, M. Hoke, and G.L. Romani, Eds, (Karger, Basel, 1990), 1-39.

"Responses to Steady-State Auditory Stimulation"
L. Kaufman, S.J. Williamson, and G.L. Romani
In: *Advances in Audiology, Vol. 6: Auditory Electric and Magnetic Fields*, F. Grandori, M. Hoke, and G.L. Romani, Eds, (Karger, Basel, 1990), 283-312.

"Alpha Suppression Related to a Cognitive Task"
B.J. Schwartz, C. Salustri, L. Kaufman, and S.J. Williamson
In: *Advances in Biomagnetism*, S.J. Williamson, M. Hoke, G. Stroink, and M. Kotani, Eds. (Plenum Press, New York, 1989), pp. 237-240.

"Differences in Alpha Suppression by Visualizing and Rhyming"
L. Kaufman, Y. Cycowicz, and S.J. Williamson
In: *Advances in Biomagnetism*, S.J. Williamson, M. Hoke, G. Stroink, and M. Kotani, Eds. (Plenum Press, New York, 1989), pp. 241-244.

"Brain Activity Related to Spatial Visual Attention"
B. Luber, L. Kaufman, and S.J. Williamson
In: *Advances in Biomagnetism*, S.J. Williamson, M. Hoke, G. Stroink, and M. Kotani, Eds. (Plenum Press, New York, 1989), pp. 213-216.

"Method for Locating Sources of Human Alpha Activity"
S.J. Williamson, J.-Z. Wang, and R.J. Ilmoniemi
In: *Advances in Biomagnetism*, S.J. Williamson, M. Hoke, G. Stroink, and M. Kotani, Eds. (Plenum Press, New York, 1989), pp. 257-260.

"Distributed Sequential Activity of the Human Brain Detected Magnetically by CryoSQUIDs"
G.A. Klemic, D.S. Buchanan, and S.J. Williamson
In: *Advances in Biomagnetism*, S.J. Williamson, M. Hoke, G. Stroink, and M. Kotani, Eds. (Plenum Press, New York, 1989), pp. 685-688.

"Advances in Neuromagnetic Instrumentation and Studies of Spontaneous Brain Activity"
S. J. Williamson and Lloyd Kaufman
Brain Topography 2: 129-139 (1989).Brain Topography, in press.

"Modulation of Spontaneous Brain Activity during Mental Imagery"
L. Kaufman, B. Schwartz, C. Salustri, and S.J. Williamson
J. Cognitive Neuroscience 2: 124-132 (1990).